Human influence on carbon fluxes in coastal peatlands; process analysis, quantification and prediction

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2003

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Chapter 6

Restoration of former wetlands in the Netherlands; effect on the balance between CO_2 sink and CH_4 source

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(Submitted to Netherlands Journal of Geosciences, December 2002)

Keywords: carbon balance, global warming potential, Holocene, mineralization, peat, water table

6.1 Abstract

Drained coastal peatlands are a source of greenhouse gas (GHG) through abundant CO_2 release caused by aerobic peat degradation. Published rates of CO_2 fixation and CH_4 release for natural peatlands suggest that areas of peat formation are a (small) net source of GHG emission because the radiative effect of emitted CH_4 exceeds the CO_2 uptake by the vegetation. It is shown here that wetland restoration of reclaimed peat areas in the western Netherlands leads to a reduction of GHG emission because the expected increase in anaerobically generated CH_4 release is much smaller than the decrease in aerobically produced CO_2.

6.2 Introduction

Plans exist in the Netherlands to reconvert agricultural peatlands into wetland-nature areas for the purpose of ecological improvement and water storage. In the context of recent discussions on compensating human induced emission of greenhouse gases (GHG)[1] and on carbon storage in the terrestrial biosphere (e.g. forests, peatlands), it is relevant to know if implementation of these plans is effective in carbon storage through fixation in peat.

Large quantities of CO_2 were extracted from the atmosphere during Holocene peat formation. Worldwide, peatlands nowadays store a substantial amount of the global terrestrial carbon pool, although regional and global estimates vary widely. According to several studies summarized by Botch et al. (1995), peatlands worldwide cover an area of 230–500 Mha storing 110–455 Gt carbon of a total soil carbon pool of about 1395 Gt (Post et al., 1982). For comparison, the current (1999) atmospheric CO_2 concentration of 367 ppmv (IPCC, 2001) is equivalent to about 780 Gt carbon.

Paleorecords show that the atmospheric concentration of CH_4, which is about 23 times as effective a GHG as CO_2 (IPCC, 2001), clearly increased during the late Holocene (Figure 1). According to Blunier et al. (1995), part of this increase is caused by the expansion of peatlands. Wetlands, which include these peatlands, are presently world's largest natural source of atmospheric CH_4.

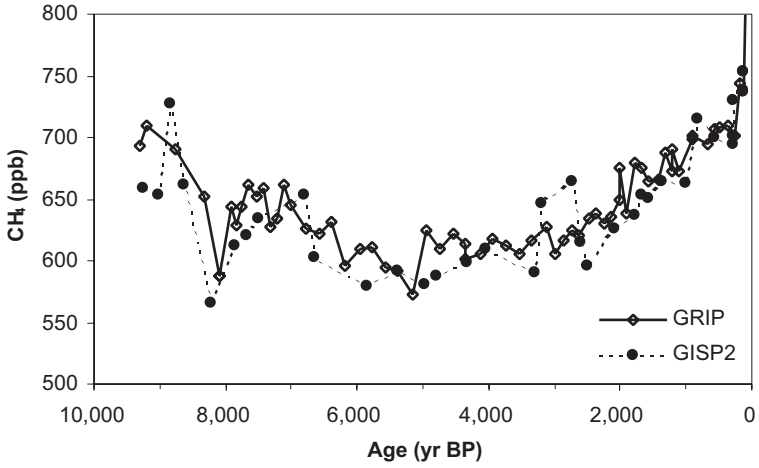

Figure 1. Changes in the atmospheric CH_4 concentration (ppb) during the Holocene. Based on GRIP and GISP2 data (Chappellaz et al.,1997; Blunier et al., 1995; Brook et al., 1996).

In the Netherlands, extensive peat areas developed during the Holocene in the north-eastern part of the country (bogs) and in almost the entire western lowland area (fens and bogs). Part of the carbon stored in these peatlands has already disappeared as a result of man's intervention (mainly digging, and oxidation due to drainage), and nowadays approximately 450,000 ha of the Netherlands consists of peatland, of which 160,000 ha is found in the western Netherlands.

If high water tables are restored, former agricultural peatlands in the western Netherlands can become a carbon sink as CO_2 will be extracted from the atmosphere by the peat forming vegetation. It is likely, however, that the emission of CH_4 will increase. This increase is dependent on the degree of inundation, since CH_4 can be oxidized before emission if the water table is (slightly) below the surface, and on the presence of other oxidants (IPCC, 2000). Results from gas-flux measurements in the slightly drained wetland-nature area Guisveld (Van den Bos & Van de Plassche, submitted) show that CH_4 emission increases with higher water tables, while CO_2 emission decreases. The process-

[1] Atmospheric emission of 1 Gt carbon (e.g. CO_2) would result in an increase of the atmospheric concentration of about 0.47 ppm.

based simulation model PEATLAND (Van Huissteden & Van den Bos, submitted) also shows that higher water tables in agricultural peatland areas lead to a decrease in CO_2 emission (reduced decomposition rates), but also to a marked increase in CH_4 emission. The model does not include carbon uptake by the (peat forming) vegetation, but it is expected that the restoration of former wetlands in the Netherlands will effectively reduce GHG emissions because the combined effect of reduced CO_2 emission and increased CO_2 uptake by the vegetation is likely to exceed the effect of the predicted increase in CH_4 emission (all fluxes expressed in CO_2-equivalents).

The overall balance between carbon fixation and release in restored wetland peat areas remains uncertain, because present-day rates of carbon uptake and CH_4 emission in natural (non-drained) peatlands and rates of CO_2 release from shallow-drained peatlands are poorly quantified. The objective of this paper is to review published quantitative data on CO_2 uptake and CH_4 release in non-drained peatlands and assess if restoration of former wetlands in the Netherlands will effectively reduce GHG emissions.

6.3 Approach

Present-day emissions from drained peatlands in the western Netherlands were obtained from field-flux measurements (Van den Bos & Van de Plassche, submitted) and from the literature. Rates of CO_2 fixation and CH_4 release in natural (non-drained) peatlands, as reported in the literature, are used to assess the effect on the carbon and GHG balance of raising the water tables in former agricultural peatland areas. These rates are recalculated into comparable units (Tables 1 and 2) and discussed in terms of accuracy and applicability for the western Netherlands. This approach gives, ultimately, the most likely answer to the question whether restoration of former wetlands in the Netherlands is an effective instrument to reduce GHG emissions.

6.4 Results and discussion

CO_2 release from drained peatlands

Most peatlands in the western Netherlands are currently being drained and act as a relatively strong source of CO_2. Closed chamber-flux measurements, performed at three selected areas within the coastal peatlands of the western Netherlands (Ransdorp, Kamerik and Guisveld) over the period November 1998 to August 2000, show clear seasonal trends in CO_2 emission (Figure 2a; for details see Van den Bos & Van de Plassche, submitted). Between-area variation in monthly CO_2 flux was small (mean standard deviation = 150 mg CO_2 m^{-2} hr^{-1}), even though peat composition, water tables and management differed considerably. Of the measured CO_2 emission 57–67 % was attributed to microbial degradation of peat. The annual CO_2 emission caused by peat degradation, as calculated by Van den Bos & Van de Plassche (submitted), amounts to 7.9–11.2 t CO_2-C ha^{-1} yr^{-1} or 29–41 t CO_2-equivalents ha^{-1} yr^{-1}.

Relatively large CH_4 fluxes (>1 mg m^{-2} hr^{-1}) were produced only at those Guisveld sites with year-round high water tables (<25 cm below surface). Like CO_2, these fluxes also show clear seasonal trends, with the largest fluxes at high temperatures in summer (Figure 2b). An average CH_4 emission rate of 0.06 t C ha^{-1} yr^{-1} (or 1.8 t CO_2-equivalents ha^{-1} yr^{-1}) was calculated for the Guisveld high water-table sites (Van den Bos & Van de Plassche, submitted).

Carbon accumulation in natural peatlands

Carbon-accumulation rates compiled by different authors for various types of peatland are listed in Table 1. Rates are expressed both in tons CO_2-C ha^{-1} yr^{-1} and in tons CO_2-equivalents ha^{-1} yr^{-1}. The table shows that most values found in the literature are below 0.5 t CO_2-C ha^{-1} yr^{-1} (or <1.8 t CO_2-equivalents ha^{-1} yr^{-1}), except the rates calculated by

Trumbore et al. (1999). These authors compared three methods to calculate carbon-accumulation rates in four different environments (collapse bog, poor fen, intermediate fen, and rich fen) within the large Thompson peatland complex (Canada). They found clear differences in carbon uptake between the sites (with rich fen having the lowest values and poor fen the highest).

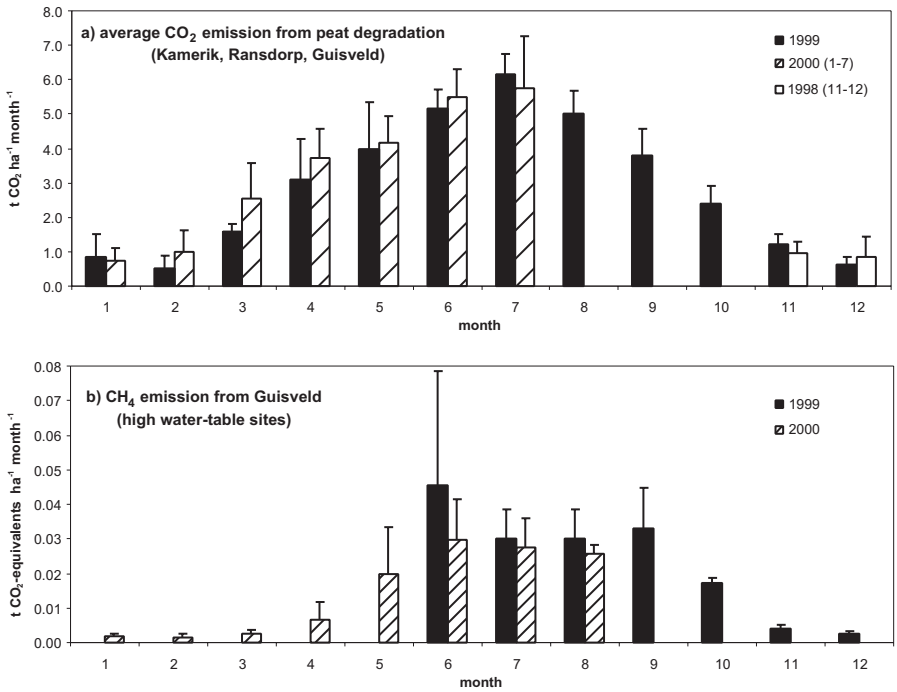

Figure 2. a) Average CO_2 emission due to peat degradation (t CO_2 ha^{-1} $month^{-1}$) over the three study areas (Ransdorp, Kamerik and Guisveld). Of the total measured CO_2 emission 57–67% is attributed to microbial degradation of peat (for this figure 62 % is used); b) CH_4 emission from the Guisveld high water-table sites (t CO_2-equivalents ha^{-1} $month^{-1}$). Error bars indicate the standard deviation. For more details see Van den Bos & Van de Plassche (submitted).

Table 1. Carbon uptake of various types of peatlands

Type of peatland	CO_2 uptake rate (t C ha^{-1} yr^{-1})	GHG balance[1] rate (t CO_2-eq. ha^{-1} yr^{-1})	References[2]
global peatlands	0.1 – 0.35	0.4 – 1.3	(GACGC, 1998)
peatlands in boreal / temperate regions	0.17 – 0.29	0.6 – 1.1	(GACGC, 1998)
peatlands in Alaska, Canada, Finland, U.S.S.R.	0.2	0.7	(Armentano & Menges, 1986)
peatlands in Europe (western, central, eastern) and in U.S. (midwest, northeast)	0.48	1.8	(Armentano & Menges, 1986)
natural Finnish peatlands	0.08 – 0.35	0.3 – 1.3	(Nykänen et al., 1995; Vasander, 1996)
fens in Thompson, Canada	0.1 – 1.8	0.4 – 6.6	(Trumbore et al., 1999)
western boreal Canada	0.14 – 0.35	0.5 – 1.3	(Kuhry & Vitt, 1996)
northern Europe	0.35 – 0.44	1.3 – 1.6	(Gorham, 1991)

[1] Rate Carbon balance–Rate GHG balance: 1 t CO_2-C ha^{-1} yr^{-1} = 3.67 t CO_2-equivalents ha^{-1} yr^{-1}.

[2] Some values are based on several other sources compiled by the named references.

Since net primary production of the vegetation was similar for all fen sites, differences in accumulation rates were attributed to differences in overall decomposition rates. Method 1 (measurement of above ground net primary production and soil respiration) and method 2 (radiocarbon) gave a range of 0.1 – 1.8 t C ha^{-1} yr^{-1}, but method 3 (direct net ecosystem production measurements) yielded a range of 0.03 – 0.65 t C ha^{-1} yr^{-1}. Trumbore et al. (1999) did not give a clear explanation for the large difference in results between the three methods, although some advantages and disadvantages of each method were discussed. One of the disadvantages of methods 1 and 3 is the fact that these are based on only a single year of measurements. Since none of the other accumulation rates in Table 1 exceeds 1.0 t C ha^{-1} yr^{-1}, the results from Trumbore's methods 1 and 2 are questioned here. Inspection of Trumbore's calculations reveals that some important components are estimates based on published data. For the radiocarbon method (method 2) only a 40 year record was used. Kuhry & Vitt (1996), on the other hand, used a 9000 year record and found carbon-accumulation rates of 0.14–0.35 t C ha^{-1} yr^{-1}. Based on several published long-term accumulation rates (0.2– 0.8 mm yr^{-1}), Gorham (1991) suggests that an overall accumulation rate in boreal and subarctic peatlands of 0.5 mm yr^{-1} seems both conservative and reasonable. This rate equals 0.29 t CO_2-C ha^{-1} yr^{-1} or 1.1 t CO_2-equivalents ha^{-1} yr^{-1} (using a carbon content for wet peat of 58 kg C m^{-3}; Gorham, 1991).

Initial rates of carbon storage in newly forming wetlands can be high (up to 1.0 t C ha^{-1} yr^{-1}; or 3.7 t CO_2-equivalents ha^{-1} yr^{-1}), but slow down over time as peat accumulates and decomposition losses begin to offset additions (IPCC, 2000; Vasander, 1996). Hydrology, nutrient status, and vegetation are inextricably linked. Most peatland soils in the western Netherlands have been drained and used for agricultural purposes, and extensive application of fertilizer has resulted in a high soil fertility. Furthermore, deposition rates of atmospheric nitrogen in the Netherlands are generally high (up to 100 kg N ha^{-1} yr^{-1}). Consequently, when water levels in these former agricultural wetlands are raised, this large nutrient availability, in combination with internal eutrophication in the peat soil (caused by decomposition), will result in relatively large above-ground biomass production and in species poverty. A species-rich fen, on the other hand, is more desirable in view of ecological improvement, but requires a more nutrient poor substrate; moreover, it is generally less productive (Koerselman, 1989).

Table 2. CH_4 emission rates from various types of natural and shallow drained wetland areas

Type of peatland	CH_4 emission rate (t C ha^{-1} yr^{-1})	GHG balance rate (t CO_2-eq. ha^{-1} yr^{-1})	Reference[2]
global natural wetlands	0.05 – 0.21	1.5 – 6.4	(GACGC, 1998)
natural wetlands in boreal / temperate regions	0.08 – 0.15	2.5 – 4.6	(GACGC, 1998)]
all northern peatlands	0.04	1.3	(Gorham, 1995)
nature reserve area Guisveld, Netherlands	0.06	1.8	(Van den Bos & Van de Plassche, submitted)
fens (Nieuwkoopse plassen), Netherlands	0.06 – 0.15	1.8 – 4.6	(Van den Pol-van Dasselaar, 1998)
virgin fen, Finland	0.15 – 0.26	4.6 – 8.0	(Martikainen et al., 1995; Nykänen, et al., 1995)
bogs and fens Minnesota, (North America), mean values	0.16 – 0.24	4.9 – 7.4	(Dise et al., 1993)
temperate bogs, Michigan (North America), range	< 0.01 – 0.57	0.1 – 17.5	(Shannon & White, 1994)
northern Hudson Bay Lowland, Canada	0.06	1.8	(Roulet et al., 1994)

[1] Rate Carbon balance–Rate GHG balance: 1 t CH_4-C ha^{-1} yr^{-1} = (1.33 * 23) = 30.67 t CO_2-equivalents ha^{-1} yr^{-1}; 23 is global warming potential of CH_4 for 100 years.

[2] Some values are based on several other sources compiled by the named references.

Another aspect of carbon accumulation in newly formed peatlands is the influence of man on the vegetation. Not only the type of vegetation, but also the amount of carbon in the system can be affected by man. Carbon accumulation in living reed vegetation, for example, amounts to 6.8 t C ha^{-1} yr^{-1} (Goosen et al., 1996). By annualy harvesting of the above-ground biomass the total carbon and GHG balances can thus (temporarily) be influenced. However, this paper focusses only on more natural (peat growing) systems and on restoration of former wetlands in which the vegetation is not actively managed. Forests, for example, are likely to be far more effective in carbon accumulation when actively managed (more carbon can be extracted from the atmosphere and be stored for a longer period). The vegetation in peat growing systems extracts CO_2 from the atmosphere and yearly adds a certain amount of carbon into the soil (peat). The above-ground vegetation (and thus the amount of carbon stored) changes substantially in the first years after restoration due to species changes, thereafter a new equilibrium sets in and the amount of carbon stored in the above-ground vegetation changes only slowly as succession continues.

CH_4 emission from natural peatlands

Published CH_4 emission rates from various types of natural and shallow drained wetland areas are listed in Table 2, expressed both in tons CH_4-C ha^{-1} yr^{-1} and in tons CO_2-equivalents ha^{-1} yr^{-1}. The range of CH_4 emission found in the literature is large: <0.01–0.57 t CH_4-C ha^{-1} yr^{-1} (or <0.1–17.5 t CO_2-equivalents ha^{-1} yr^{-1}). Shannon & White (1994) found clear differences in CH_4 emission between two bog areas in Michigan (USA). They measured very large annual CH_4 fluxes (0.5–0.57 t C ha^{-1} yr^{-1}) at three sites in Buck Hollow, characterized by water tables at or above the peat surface for major portions of the year and high (summer) soil temperatures (20–25 °C). Four measurement sites at an other Michigan bog area, Big Cassandra Bog, showed much lower annual fluxes (0.0015–0.35 t C ha^{-1} yr^{-1}) over a period of three years, mainly as a result of lower water tables. Highly dynamic water tables and differences in plant communities at the Big Cassandra Bog sites, on the other hand, resulted in large inter-annual and spatial variability in fluxes. Thus, both high water tables (in combination with high temperatures) and plant communities exert a primary influence on the CH_4 flux . The presence of CH_4-transporting plants (like vascular sedges) and the amount and quality of organic carbon substrates provided by the vegetation strongly determine how much CH_4 can be emitted from peatlands (Shannon & White, 1994).

Van den Pol-Van Dasselaar (1998) measured CH_4 emission rates of 0.06 – 0.15 t C ha^{-1} yr^{-1} in the western Netherlands (wetland-nature area Nieuwkoopse Plassen) and concluded that an average CH_4 emission from grassland on peat soil of 0.1 t C ha^{-1} yr^{-1} (or 3.1 t CO_2-equivalents ha^{-1} yr^{-1}) is reasonable. Gas-flux measurements in the wetland-nature area Guisveld resulted in an average CH_4 emission rate of 0.06 t C ha^{-1} yr^{-1} (Figure 2b) (Van den Bos & Van de Plassche, submitted). Since the latter area is shallow drained and therefore not an actively growing peatland, it is likely that CH_4 emission rates will exceed 0.06 t C ha^{-1} yr^{-1} (or 1.8 t CO_2-equivalents ha^{-1} yr^{-1}) when the water tables are raised to or above the surface. Although a wide range of CH_4 emission rates are reported in the literature (Table 2), values presented here (especially those for the western Netherlands) show that CH_4 emission rates of >0.1 t C ha^{-1} yr^{-1} (or 3.1 t CO_2-equivalents ha^{-1} yr^{-1}) are likely to occur sometime after these agricultural peatland areas in the western Netherlands have been reconverted into undrained wetland-nature areas.

Balance between CO_2 sink and CH_4 source in natural peatlands

In calculating the balance between CO_2 uptake and CH_4 release, CH_4 is taken as a 23 times stronger GHG than CO_2. Lashof & Ahuja (1990) questioned if it was justified to use the global warming potential (GWP) as a multiplying factor because it did not fully take into account the much shorter residence time of CH_4 in the atmosphere (14.4 yr) compared to that of CO_2 (230 yr). Nowadays, however, this difference in atmospheric lifetime is

accounted for by calculating the GWP's over different time horizons (IPCC, 2001). For gases with short atmospheric lifetimes, their effects are greatest when measured over a short time span. As the time span lengthens, their total effect diminishes. Thus, the estimated direct GWP of any particular gas is highest for time periods shorter than its atmospheric lifetime and lower for periods that are longer. For CH_4 the GWP diminishes from 62 for a period of 20 years, to 23 for a period of 100 years, to 7 for a period of 500 years (IPCC, 2001).

On the basis of the above discussion of rates of CO_2 fixation and CH_4 release in natural peatlands, it is concluded that restoring former natural peatlands (presently grasslands) can result in a net increase in GHG emission since long-term carbon-accumulation rates (i.e. peat formation) are generally below 1.8 t CO_2-equivalents ha^{-1} yr^{-1} (or <0.5 t CO_2-C ha^{-1} yr^{-1}) and CH_4 emission from anaerobic degradation of organic matter is likely to be >3.1 t CO_2-equivalents ha^{-1} yr^{-1} (or >0.1 t CH_4-C ha^{-1} yr^{-1}).

Balance between CO_2 sink and CH_4 source in inundated, formerly drained peatlands

It is likely, however, that the restoration of drained peatlands into wetlands in the western Netherlands will effectively reduce GHG emissions, due to the fact that most peatlands are presently being drained and act as a relatively strong source of CO_2. The largest effect of inundating drained peatlands in the Netherlands will be the inhibition of the oxidation of organic matter and therefore a reduction of the CO_2 emission. When the CO_2 emission caused by peat degradation (7.9–11.2 t CO_2-C ha^{-1} yr^{-1} or 29–41 t CO_2-equivalents ha^{-1} yr^{-1}), as calculated by Van den Bos & Van de Plassche (submitted), is completely reduced due to inundation, the expected increase in CH_4 emission is relatively small and a net reduction in GHG emission will occur. Note, however, that peat oxidation can be effectively suppressed by inundation only when peat forming conditions are restored, because shallow drained peatlands can emit equal amounts of GHG as deeper drained peatlands (Van den Bos & Van de Plassche, submitted).

6.5 Conclusions

In newly formed wetlands, rates of carbon storage can be high (up to 1.0 t C ha^{-1} yr^{-1}), but rates slow down over time (probably to values <0.5 t CO_2-C ha^{-1} yr^{-1} or <1.8 t CO_2-equivalents ha^{-1} yr^{-1}) as peat accumulates and decomposition losses begin to offset additions. CH_4 emission rates in peatlands are dependent on many environmental variables (e.g. temperature, presence of oxidants) and vary widely. When water tables are at or above the surface, however, a CH_4 emission >0.1 t C ha^{-1} yr^{-1} (or 3.1 t CO_2-equivalents ha^{-1} yr^{-1} using a GWP of 23 for a period of 100 years) is likely to occur. Based on these rates of CO_2 fixation and CH_4 release, new peatlands can thus become a (small) net source of GHG emission. However, when the present situation of peat drainage in the western Netherlands is taken into account, the large CO_2 emission by aerobic degradation (7.9–11.2 t CO_2-C ha^{-1} yr^{-1} or 29–41 t CO_2-equivalents ha^{-1} yr^{-1}) will be suppressed by inundation. The conclusion is therefore, that the restoration of former wetlands in the Netherlands will effectively reduce GHG emissions, because the inhibition of present-day peat oxidation, and the resulting decrease in CO_2 emission, will largely exceed the increase in CH_4 emission (expressed in terms CO_2-equivalent radiative forcing).

6.6 Acknowledgements

I thank Pier Vellinga and Orson van de Plassche for comments on a draft of this paper.

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